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1 CHANNEL MODIFICATION [HIGH X 2]

1.1 Introduction

Aquatic habitat formation is directly related to channel processes and channel form. Where these processes or forms are out of balance with their natural inputs or where they have been disturbed, modification of the channel may be an appropriate technique, as part of an overall watershed management plan, to restore a sustainable natural channel and floodplain. This can be accomplished through the alteration of channel profile, planform, cross-section, or through the relocation of a stream segment or an entire reach.

1.1.1 Description of Technique

Channel modifications can be implemented to restore or improve aquatic and riparian habitat. Modifications may include direct restoration (reconstruction of a channel) or incremental process restoration (installation of a natural structural feature to induce change in a channel). Channel modifications can also be used to restore bank stability and reduce bank erosion, which may greatly improve aquatic habitat and water quality (Refer to Streambank Protection Guidelines). Channel modification techniques may affect the local slope, length, sinuosity, and dimensions of the channel, as well as alter basic channel processes related to sediment transport, and are very useful for treating the underlying causes of habitat degradation. They should, therefore, be considered as a potential solution where there are chronic problems.

The goal of channel modification is to restore or create an equilibrium condition in the stream reach. A channel in equilibrium is one that has adjusted to the physiographic conditions (e.g., climate, geology, discharge, sediment supply) of its watershed. Keep in mind that throughout this document the terms "stable channel" and "equilibrium channel" do not necessarily mean a channel without erosion. A channel in equilibrium may still erode naturally as the channel migrates across the floodplain.

A channel in equilibrium can become unstable following some human or natural disturbance, such as changes in hydrology or sediment loads, extreme hydrologic events, and construction of channel confinements. Stream restoration plans, then, strive to attain or restore a stable channel condition, or equilibrium, based on the current and future hydrology and sediment supply of the stream. Natural events that create disturbance are essential to providing and maintaining habitat (see Chapter 2 and Geomorphology Appendix), but in some cases natural events may also lead to local disequilibrium. Whether it is appropriate to address this through channel modification will depend on the condition of the watershed and the status of the fish populations within that watershed.

Channel modifications are typically implemented through alteration of planform, cross-section, or profile. Channel planform refers to the shape of a channel in map view and defined by sinuosity and meander characteristics. Cross-section refers to the shape, width and depth of channel from bank to bank and across the floodplain. Channel profile refers to the slope, and variability of the slope, along the channel bed.   Planform, cross-section, and profile are integral components of channel process, and typically, altering one aspect will affect the process of others.   Furthermore, alteration of any of these typically results in a change in the hydraulic and sediment transport characteristics of the channel.   Process diversity and functional habitat is dependent upon variability in all three of these channel components.

Because all channel-modification techniques result in changes to channel process, a thorough understanding of fluvial geomorphology is an essential component of developing channel modification projects. Refer to *Geomorphology Appendix* and to Chapter 2 for further discussion of channel planform, cross-section, profile, and channel stability and equilibrium.

1.1.2 Physical and Biological Effects

The potential effects of channel modification must be carefully assessed for a project reach. If implemented correctly, channel modification can restore natural features that fit the current and/or future conditions of the watershed. Excessive erosion can be restored to a gradual and predictable rate, with habitat and other ecological conditions optimized. When properly applied, channel-modification techniques can result in a one-time, cost-effective fix, preferable by far to the periodic and chronic-fix alternative of treating a problem symptom by symptom.

However, without a clear understanding of the complexities of channel-modification techniques and of the stream channel in question, problems may arise. Channel modifications invariably result in changes in the energy balance and hydraulics of the channel, which control sediment transport by changing flow velocity, scour, and depositional processes. For example, a decrease in stream gradient associated with adding a meander bend to a straight reach (lengthening the channel), results in lower stream energy and may cause aggradation due to sediment deposition and associated increased bank erosion. Therefore, careful analysis and design are required. Chapter 2 and the Geomorphology Appendix provide greater detail and discussion of channel dynamics the relationship between channel process and equilibrium, and between channel process and channel form.

Add discussion of effects of modifications on water surface elevations – flood flows, etc., and to property

1.1.2.1 Biological Considerations

The purpose of channel modifications is to restore natural process to a channel, which in turn promotes biological health. Physical and biological effects of channel modifications are intimately related. Because aquatic habitat is so dependent upon the stream processes and resultant channel form, benefits to the living community will depend on the degree of success of promoting equilibrium conditions of natural processes. Successful restoration of a stream to a more stable, natural shape can have tremendous benefits for fish and wildlife by providing natural variable processes and functions which promote a diversity of habitat.

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Because of the scale of disturbance (reconstruction) associated with channel modification projects, however, the risk of unanticipated impacts can be very high, particularly when finished projects do not meet restoration objectives. Furthermore, the physical construction of channel modifications can cause severe short-term disturbance to aquatic habitat and organisms.

Benefits of channel modifications to aquatic habitat and organisms are virtually infinite in number, as successful restoration will result in all possible benefits normally provided by a natural channel system. Benefits may include the following:

- Improved scour and sorting of gravels for spawning habitat
- Greater diversity in channel bedforms to provide diverse habitat
- Greater diversity in channel hydraulics and velocities to provide diverse habitat
- Improved nutrient cycling and exchange within the channel and between the channel and hyporheic zones
- Greater potential for refuge during high and low flows

Impacts to aquatic habitat and organisms include the following:

- Short-term disturbance or displacement of macroinvertebrates, amphibians, fish and some nesting birds due to in-stream disturbance, increased turbidity, fine-sediment deposition, channel abandonment and loss of riparian vegetation associated with construction.
- Channel modifications involving new channel construction may result in temporary loss or imbalance of nutrients and foods in addition to displacement of physical habitat.

1.1.3 Application of Technique

Channel modifications can be used to address an infinite variety of process- and function-related habitat problems.

- Aggradation or degradation;
- Impacts of grazing or forest practices;
- Impacts of development, including changes in hydrology and channel constrictions;
- Human impacts to the channel and its banks;
- Excessive bank erosion (Refer to Integrated Streambank Protection Guidelines);
- Floodplain and side-channel function;
- Fish passage; or
- Limited aquatic habitat.

1.1.3.1 Channel Profile Change

Channel profile is the slope, or gradient, of the channel bed. Channel profile will change as a result of any activity that changes the bed elevation at a point. If the bed elevation is changed at a point or series of points, the channel profile must also change over the reach that contains that point. In addition to changing the slope of a channel by adjusting the bed elevation, the depth of a channel can also be changed by raising or lowering its bed elevation along the profile, without changing the slope within a reach.

Channel profile greatly influences the energy of a stream, and therefore its ability to transport sediment. Steeper channels have greater energy and capacity to transport sediment for a given discharge and channel dimension. As such, modifications to channel profile can be used to facilitate restoration of equilibrium sediment transport processes.

Channel profile changes implemented to improve habitat include:

- Installation of removal of culverts or drop structures at elevations either above or below existing channel bed elevation.
- Change of channel length, associated with changes in channel planform.
- Change in base level elevation, such as removing a dam.
- Dredging or filling a channel to compensate for in-channel sediment storage imbalances.
- Installation of woody debris jams, log drops, or other roughness elements.

Two common circumstances that warrant consideration of channel profile treatments include degrading channels and channelized, or straightened, channels. Degrading channels have a greater flow capacity so that an even greater discharge level is needed for over bank flow. Channels that are confined to ten-year or greater flood flows have sufficient energy to move large quantities of material. Massive channel erosion can occur if flood flow is confined within the channel during a 20-year or even 50-year flood event. An increase in bed elevation can aid in reconnecting the degraded channel to its floodplain. Degraded channels that are reconnected to an active floodplain become more stable because water depths and velocities in the channel are reduced relative to those that are causing incision. If flood flows spread out over the floodplain during relatively frequent floods (one- to five-year return-interval events), channel erosion may be minimized. Therefore, raising the elevation of an incising channel bed should be seriously considered as an effective means of stabilization.

Channel slope can be increased by shortening the channel or decreased by lengthening the channel, depending upon the type of desired impacts to a reach. Channel shortening can best be accomplished by straightening a channel through a reach (reducing sinuosity). Restoring a single meander or adding even more meanders to a previously straightened channel can lengthen the channel. Treatments can also include the installation of drop structures that change the channel profile by increasing the channel-bed elevation at a certain point. This reduces upstream slope and increases downstream slope.

1.1.3.2 Channel Planform Change

On a broad scale, numerous channels may occupy a single valley. The relationship among channels within a valley and their character is referred to as "channel pattern".

The most common channel patterns that occur naturally are straight, meandering, and braided (Figure 6-1 from ISPG). Most channel modification efforts are focused, however, on single channels, whose character is described as "planform". Channel planform is the shape of a single channel looking down on it from above (referred to as "plan view").

Several local and watershed-wide factors determine the planform of a specific river reach, including geology, hydrology, slope, bank structure, and sediment and large woody debris characteristics. When any one of these factors changes enough to cross a threshold value, channel planform change may be abruptly initiated, and usually results in a less stable channel system. In some cases, relatively small changes in climate or land use may trigger large changes in channel characteristics of natural streams. For further discussion of the concept of geomorphic thresholds, refer to *Geomorphology Appendix*.

One common descriptor of planform is "sinuosity," which is a measure of channel length relative to valley length. Whether a channel passes relatively straight through a valley or crisscrosses the valley several times is a function of its sinuosity. Sinuosity is a function of slope (profile), and vice versa. Adjustments to either slope or sinuosity will result in changes to the other in most circumstances. The exception to this rule is in channels with significant grade breaks, such as small dams or other drops, where slope can be changed significantly by removing the grade break. This type of change would not directly affect the channel's sinuosity. Additionally, changes to a stream's profile or plan will result in a change in its energy and sediment-transport capacity.

Channel planform changes implemented to improve habitat include:

- Reconnection or reconstruction of historic meanders in channelized reaches.
- Changes in channel profile resulting in change in sinuosity.
- Redirection of channel to improve process while accommodating infrastructure limits.

Channel planform modification is a major undertaking, involving reconstruction of the channel bed, habitat features, channel banks and floodplain. Channel planform modification should be considered only where the existing planform is in disequilibrium and the watershed causes of that disequilibrium have been addressed, or can be compensated for in the channel design.

1.1.3.3 Channel Cross-Section Change

Changing a channel's cross-section involves altering its width, depth, or channel shape, and can include modification of channel banks and bars. Cross-section modifications are most commonly applied to the bankfull channel. Cross-section changes directly impact the capacity of a channel either by changing the cross-sectional area, or by changing the width to depth ratio, which can affect channel velocity. These changes in capacity and velocity may have an impact on sediment transport as well.

Channel cross-section changes implemented to improve habitat include:

- Changing cross-section dimensions to affect a change in channel hydraulics.

- Changing cross-section dimensions to affect a change in channel capacity, such as promoting overbank flow.
- Narrowing or widening a channel to effect a change in sediment transport by altering channel hydraulics.
- Creation of asymmetrical cross-sections to promote habitat and hydraulic diversity.
- Gravel bar scalping or removal in aggrading channels.
- Removal of levees. For further discussion of levee removal, see Techniques – Levee Removal and Setback.

Cross-section modifications can be accomplished by:

- Encouraging the channel to narrow itself by restoring vegetation and/or debris collection at the site or the addition of in-channel roughness elements.
- Installation of in-channel structures, such as groins or barbs (refer to Integrated Streambank Protection Guidelines).
- Physical reconstruction of stream channel.
- Cross-section modification may also involve altering a channel bank slope to provide greater cross-sectional area. This involves excavating a bank and reshaping it from a steep or vertical face to a lower slope. Bank reshaping is a necessary component of several techniques described in the Integrated Streambank Protection Guidelines and provides a number of benefits to the stream system. Refer to the ISPG for further discussion.

The removal of gravel bars is often perceived to be a beneficial cross section adjustment; however, its effectiveness is generally limited and temporary at best. Point bars are depositional features located on the inside of meander bends. While point bars and eroding banks evolve together, one does not generally create the other. They are simultaneous products of the channel migration process. The channel planform creates the bend hydraulics; as the distribution of shear stress causes scour on the outside of the bend, it creates deposits on the inside of the bend.

1.1.3.4 Channel Relocation

Channel relocation involves construction of an entirely new channel section or reach, usually parallel to the existing channel within a valley bottom. Relocation may be implemented to move a channel away from a source of contamination or confining infrastructure, or to foster the development of a new, stable channel within existing healthy riparian buffers elsewhere in the floodplain. Channel relocation may involve recreation of existing channel characteristics, including channel profile, planform, and cross-section, or may involve creation of new planform and cross-section to account for differing site conditions or other project objectives. Design complexity in relocation projects is often reduced, relative to modifying existing channels, by virtue of having a “clean slate” to work with. Furthermore, implementation can be greatly facilitated by building the new channel without flowing water conditions.

1.2 Scale

Channel modification methods can be used at virtually any scale, from site-specific to multiple continuous reaches of a river, and on any size stream channel. Site-specific channel modifications may include bedform modifications or removal of structures to improve passage or increase habitat complexity. Reach-scale modifications may include channel relocation or planform modification. Large-scale modifications may include removal of levees through long reaches of a valley (refer to Levee Removal and Setback Technique) or the passive modification resulting from allowing free channel migration channel within an established meander corridor. Similarly, changes in base level may differ substantially in scale. A small culvert controls base level on a stream, and its removal may have little impact on channel process. In contrast, changes in base level resulting from removal of a dam may result in or require large-scale channel modifications.

In addition to spatial scale, channel modification can be considered in the context of temporal scale. Passive modifications, such as promoting channel narrowing through re-establishing riparian and bank vegetation, may require years or decades before full benefits are realized, while active reconstructive approaches may bring about desired process and function immediately or on much shorter time scales.

1.3 Risk and Uncertainty

1.3.1 Risk to Habitat

Channel-modification projects should be designed to provide aquatic and terrestrial habitat benefit. However, large-scale channel modification may result in significant short-term adverse impacts to, and loss of, habitat, fish and wildlife due to disturbance. Months to years may be required for full recovery of some habitat components and recolonization. There is a risk that a poorly designed channel-modification project may have a negative effect on habitat rather than a positive one. A newly constructed channel that is not well protected by vegetative structure may be negatively impacted by high-flow events during the first several seasons. A contingency plan should be in place to deal with unexpected consequences.

1.3.2 Risk to Infrastructure

Channel modification may result in risk to infrastructure if inappropriately designed due to the complexity of accurately predicting relationships among various channel attributes in design and implementation (e.g. raising the channel bed elevation can increase the local flood risk). However, their intent is to improve channel stability and, thereby, reduce risk to infrastructure.

1.3.3 Reliability/Uncertainty in Technique

Because all channel-modification techniques result in changes to channel process, there is a risk that an inappropriate design or unanticipated conditions will cause a project to fail. It is difficult to predict the response of channel modifications to the hydraulic character of the reconstructed and adjacent reaches as well as the sediment transport through the reach. A thorough understanding of fluvial geomorphology is an essential component of developing channel modification projects. Refer to *Appendix X, Fluvial*

Geomorphology for further discussion of channel planform, profile, cross-section, and channel stability and equilibrium.

Channel modification design requires consideration of many design components, including sediment transport, habitat, bed substrate, channel hydraulics, and hydrology, and an understanding of many disciplines, including geomorphology, biology, hydrology and engineering to name a few. Design components are discussed further under "Methods and Design". The risk and uncertainty associated with conducting a channel modification project can be greatly reduced by adequately accounting for many interdependent design components and by involving specialists from all related disciplines.

1.4 Data Collection and Assessment

Data collection and assessment will be highly dependent upon the intent of the project, the nature of the channel, and the modifications to be implemented. However, because any alteration of channel character can have far-reaching impacts, it is essential that data collection and assessment for channel modification be comprehensive and allow for careful consideration and analysis of impacts and effects.

1.4.1 Field Data Collection

Channel modification involves consideration of the geomorphic character and behavior of the stream, which is highly dependent upon the character of its watershed. Channel modification design should include reach assessment at a minimum, and watershed assessment in most cases. Reach and watershed assessment are detailed in Chapter 3. Reach assessment will require the collection of field data. Field data should include the following at a minimum:

- Topography of project area and adjacent reaches, including floodplain and terraces
- Survey of plan, profile, and cross-sections of existing reach, adjacent reach, and reference reach
- Sediment characterization of bed and bank materials and of sediment sources
- Documentation of physical, regulatory, social, and economic constraints and project limits
- Mapping of soil materials and vegetation
- Documentation and mapping of existing habitat features
- Evaluation and documentation of existing habitat types and condition with a description of major plant species and communities, and terrestrial, and aquatic wildlife habitat
- Photo documentation of site from permanent benchmarks that will not be disturbed by the project
- Data from reference area

1.4.2 Data to Assess

Data assessment should include:

- Determination of channel forming discharge and flood discharges
- Flood and overbank flow profiles of existing hydrologic conditions
- Volume and gradation of sediment supply
- Hydraulic conditions, including velocity and shear of existing channel
- Detailed reach and watershed assessment (refer to Chapter 3)

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1.5 Methods and Design

1.5.1 General Approaches to channel modification design

A detailed discussion of channel modification design methodologies is beyond the scope of this document because of the relative complexity and variability in channel-modification projects. Details of specific channel modification projects consist of many of the techniques described in this guideline. A qualified geomorphologist should be consulted to help evaluate the necessity and applicability of major channel-modification work and to assist in design. Additionally, qualified professional engineers should also be consulted to evaluate the potential risks to safety, property, and infrastructure associated with channel modification projects.

An analysis of historic photos and maps can provide vital information for channel-modification work. However, if existing channel condition is a result of changed hydrology or sediment supply, then historic photos cannot provide a basis for reconstruction. Careful analysis of the watershed should accompany any channel modification work to determine if there has been significant alteration of the watershed hydrology. If urbanization, timber harvest, grazing, agriculture or other human activities have affected the watershed, the hydrology may be significantly and permanently altered. Natural changes such as fire should also be considered. Selection and design of channel-modification treatments should be based on historic photos only where changing watershed conditions can be accounted for, or where the watershed has already been restored to historic conditions. In any case, future anticipated conditions are a critical element of any channel modification design.

There are three general approaches to channel modification designs: Analog, Empirical, and Analytical. The Analog approach involves replicating channel characteristics from historical data on the project site or from information gathered from a similar, stable channel and assumes those reference channels are in equilibrium sediment and hydrologic conditions. Empirical design uses equations that relate various channel characteristics derived from regionalized or “universal” data sets, and also assumes equilibrium sediment and hydrologic conditions. Analytical design makes use of the continuity equation, roughness equations, hydraulic models, and a variety of sediment transport functions to derive equilibrium channel conditions, and thus is applicable to situations where historic or current channel conditions are not in equilibrium, or where applicable analogs or empirical equations are unavailable. Skidmore, et al. 2001 provides a detailed discussion of the applications and limitations of these varying approaches. Many channel modification designs will incorporate aspects of all three.

1.5.2 Design Methodology

Channel modification design may use any of the approaches described above, or a combination of the three. Project objectives, site conditions, and availability of an appropriate reference reach or sediment data may dictate what approaches are applied. For further information regarding contemporary approaches and limits of knowledge of channel modification design methods, refer to the following documents:

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1. Aquatic Habitat Guidelines *Channel Design White Paper* (include web link here)
2. Brookes, A., and F.D. Shields, 1996. River Channel Restoration: Guiding Principles for Sustainable Projects. John Wiley and Sons, Ltd.
3. Fripp, J.B., Copeland, R.R. and Jonas, M. 2001. An overview of the USACE Stream Restoration Guidelines. In: *Sediment: Monitoring, Modeling and Managing*, Proceedings of the 7th Federal Interagency Sedimentation Conference, Reno, NV, March 25-29 2001.

Regardless of the specific approach applied, channel modification design should follow the following sequence:

1. Define project objectives
2. Site survey and geomorphic study
3. Identify site constraints/limitations
4. Biological resource assessment and risks to key species
5. Establish design criteria
6. Determine design discharge
7. Evaluate sediment transport implications
8. Apply one of three design approaches, or combination of approaches

Placeholder – paragraph describing channel modification design as an iterative process. Design is an iterative process, whereby the design or determination of one design component affects the design of other components. There is no single and logical series of design tasks that can be followed sequentially to arrive at a final design.

1.5.3 Channel Modification Design Components

Placeholder – introductory paragraph to design components will be written at 90% effort.

Channel modification designs involve consideration of many processes that act in concert and result in dynamic channel form and aquatic habitat.
The design of channel modification projects requires expertise from a number of disciplines.

1.5.3.1 Hydrology

There are three types of flows to account for that may influence design of channel modifications, described below. The Hydrology Appendix includes further details on these flows, and how to determine values for these flows for a given project.

1. Dominant discharge is the discharge that over time does the most work, in the form of sediment transport, erosion and deposition, on the channel. In streams in equilibrium, this discharge is commonly equivalent to bankfull discharge. As such, it is the discharge that should be used to determine the size of the bankfull channel dimensions.
2. Low flow is the base level of flow in the channel when the stream is not subjected to

runoff from storms or snowmelt. Low flow should be used to design and size many habitat components including refuge and pools.

3. Flood flow is any low-probability flow that exceeds the capacity of the channel and inundates the floodplain or other adjacent areas. Flood flows, such as the 100-year flow, may be the basis of design for some channel components that are otherwise unrelated to habitat, but which may be required for regulatory purposes. In many urban areas, channel modification projects cannot cause an increase in water surface elevations during flood flows.

In addition to the in-channel flows, hydrologic considerations for habitat design may include hyporheic and groundwater flow and interaction. The hyporheic zone is the transition area between surface flow and groundwater and is important to the supply and sink of nutrients within the channel, for temperature regulation within the channel, and for moderating variations in streamflow. While the importance of this zone is acknowledged, the opportunity to actively account for and manage the influence of this zone in habitat projects is very small due to the limits of understanding and the extreme variability of hyporheic conditions spatially and temporally.
Hyporheic zone and conditions are detailed in the Hydrology Appendix.

1.5.3.2 Hydraulics

Hydraulics refers to the forces generated by moving water within the channel. Consideration of hydraulics is essential to successful design of stream habitat, as factors such as velocity, shear, and flow vectors determine sediment transport rates, scour depths, depositional areas, gravel sorting, and fish passage. The Hydraulics Appendix provides detailed descriptions of analyses and methods for measuring and determining hydraulic variables in the design process.

Hydraulic models also provide a valuable tool for determining channel geometry. These models can be used to determine the dimensions of a channel and to determine inundation periods for floodplain overflow, refuge flooding, and other areas of off-channel inundation. The models and their application are also detailed in the Hydraulics Appendix.

1.5.3.3 Riparian Revegetation

Riparian vegetation provides stability to the lateral channel boundaries, nutrients to the stream, and a source of wood debris. Revegetation should be an integral part of most channel modification projects, and is often not given due consideration. The long-term stability of a channel, particularly a modified channel, may be highly dependent upon stabilizing riparian vegetation on the channel banks. The use of vegetation in reconstructed channel banks is detailed in the Integrated Streambank Guidelines, as well as in the Riparian technique and Appendix of this document.

1.5.3.4 Fluvial Geomorphology

Fluvial geomorphology refers to the processes acting within and resultant forms and character of stream and river systems. Watershed inputs to the stream that determine channel form include hydrologic and sediment inputs. These inputs, and the character of boundary materials of the channel, including bank vegetation, determine channel form, and available habitat and habitat quality. This science is perhaps the most important component of channel design, and often the most difficult to adequately quantify and evaluate. Stream habitat design will benefit greatly from consideration and evaluation of the geomorphic character of the stream, and of the geomorphic processes shaping the stream. Concepts in fluvial geomorphology that are pertinent to channel design are discussed in Chapter 2 and detailed in the Geomorphology Appendix.

1.5.3.5 Sediment and Bed Substrate

Sediment in the context of channel modifications includes everything from boulders to sand and suspended sediments. Channel modifications can include components designed to manipulate existing sediment transport and deposition within a channel reach and through the reach. Sediment within a stream can both enhance and provide habitat (e.g. spawning gravels) and degrade habitat (e.g. fine-grained sediment within spawning gravel). Characterization and design of sediment transport is an integral component of channel modification design. The size and shape of the channel will determine to a large extent what size material will be transported and sorted within the channel, and thus will influence the viability and quality of habitat, particularly spawning habitat and aquatic food production.

Many channel modification projects in alluvial channels require the import and installation of bed substrate. Bed substrate is essential to provide protection from erosion of the channel bed, and to provide spawning gravels. The import and installation of bed substrate requires careful attention to size gradations such that the gravel will provide both spawning value and bed protection. This is typically accomplished by incorporating a gradation of material that contains both mobile (at bankfull flow) and immobile gravels. The degree to which the gradation is mobile or immobile will depend on site-specific channel character, underlying and adjacent materials, and the degree of acceptable risk. In some instances, for example in urban watersheds that have limited or no supply of gravels in historically alluvial systems, the bed substrate may have to be immobile to prevent channel degradation. Protection of the channel will have to be balanced with the need for mobile spawning gravels.

The design criterion for bed mobility is usually related to a channel discharge. In naturally functioning stream systems, bed substrate designs commonly use a target of the D_{50} particle size mobile at bankfull conditions. Thus, at bankfull conditions, 50% of the bed substrate material would consist of a size that could mobilize, and 50% would be immobile. How much material actually mobilizes will be a function of scour depth and bed substrate size and the particular hydraulic conditions at any given site. This allows for gravel sorting processes that are essential for maintenance of spawning gravels. In contrast, in an urban environment with no natural replacement of streambed gravels, all streambed substrate may be designed to be immobile at all flows in order to protect against bed degradation. Methods for determining substrate mobility are presented in the Hydraulic Appendix and the Sediment Transport Appendix.

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The science of sediment transport straddles the disciplines of engineering and fluvial geomorphology. Typically, engineers conduct the methods and models used to analyze sediment transport. However, fundamental principles of geomorphology are also dependent upon characterization of sediment movement through the system. The Sediment Transport Appendix presents methods for measuring and quantifying sediment transport, and for applying these methods to design of channel modifications.

1.5.3.6 Bank Reconstruction

A stream channel is defined at its margins by its streambanks. Most channel modification activities will require reconstruction of channel banks on one or both sides. Even modification projects that affect only the channel profile should consider the impacts of the activities on the channel banks. Any change in the physical character of a channel typically results in changes to the hydraulic conditions within the channel, and thereby may affect the stability of existing channel banks. The best conceived channel modifications could fail due to poorly designed or constructed streambanks. The design and reconstruction of streambanks for channel modification often requires an equal effort in design, construction, and expense to the channel modifications themselves.

Design and construction of stream channel banks is the focus of the Aquatic Habitat Guidelines' Integrated Streambank Protection Guidelines. Refer to the ISPG for detailed discussion and information on design of streambanks.

1.6 Project Implementation

1.6.1 Permitting

Permitting channel modification projects will be very site- and project-specific. Channel modification invariably involves physical disturbance of the channel, which disrupts habitat and water quality at the site and downstream. A comprehensive discussion of permitting requirements is inclu,ded in Chapter 4.6 of this document. Because most channel modification projects involve the movement, redistribution, or installation of material within the channel, permitting for these projects is typically comprehensive and the permitting process rigorous, particularly if conducted in streams affected by ESA.

Many channel modification projects may qualify for a streamlined process for fish habitat enhancement. Smaller projects conducted as part of grander coordinated watershed restoration efforts may be facilitated by an expedited permit application. Both of these alternatives are part of the general JARPA permit process. Refer to Chapter 4.6 for details about this streamlined permit process.

1.6.2 Construction

Placeholder – if there will not be a construction appendix for SHRG, then this section should be substantial and comprehensive. If there is a construction appendix for SHRG, then the appendix should cover everything. Content of this section to be completed after review of Construction Appendix.

Construction of channel-modification projects requires careful sequencing of work phases.

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Construction steps may include (not necessarily in this order): constructing a diversion channel; diverting stream flow; rescuing fishes from areas to be dewatered; dewatering; providing access for and stockpiling imported materials; waste materials and transitional redistributed materials; constructing streambanks; installing erosion and sediment control; constructing and installing habitat features; and redirecting flow into the modified channel. Further discussion of these components can be found in Appendix X, *Construction Considerations*.

Fish trapping and relocation may be required to remove fish from the project construction area. The lower end of an existing channel might be left open and connected so there is in-stream habitat until the new channel is established with vegetation. A new channel may be left exposed for a winter so it can weather before flow is diverted into it.

1.6.2.1 Materials Required

Construction of channel-modification projects will generally require dewatering of the channel either by diverting all flow or by isolating parts of the channel during construction. Dewatering is essential to facilitate construction and to control sediment inputs to the stream. Channel-modification projects are constructed using native materials available on site, through stockpiling, redistribution and rearrangement of existing channel materials. If not already present in the channel, large, woody debris may have to be supplied from elsewhere. Many channel-modification projects require reconstruction of channel banks. Refer to specific bank-protection techniques provided in the *Integrated Streambank Protection Guidelines* details of bank construction.

1.6.2.2 Timing Considerations

Channel modification often requires complete dewatering. Consequently, the work should be timed to occur during low-water periods. Critical periods in salmonid life cycles, such as spawning or migration, should also be avoided. Additionally, critical periods for other species dependent upon the channel system, including amphibians and birds should be avoided. In-stream work windows vary among fish species and streams. Contact The Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows. Further discussion of construction timing and dewatering can also be found in Appendix *Construction Considerations*.

1.6.3 Cost Estimation

Channel-modification project costs are site and design specific and vary according to the size of the channel. Reconstruction and relocation projects may range from $50 to $1000 per foot of channel (including reconstructed banks and dewatering), depending on the size of the channel and complexity of modification techniques. Key cost items will include dewatering systems, imported materials, heavy equipment, construction direction, and bank reconstruction. Dewatering will be a significant cost for many channel modification projects because it requires, in most cases, complete dewatering of the entire channel or at least half of the channel. The need to import materials for any component of the modification will greatly increase implementation costs. If an entirely new channel is being constructed, or an historic channel is being reconstructed, all of the work can be done in the dry, thus dewatering is not necessary until the water is turned out of the old channel reach and into the new one.

Many channel-modification projects will require reconstruction of channel banks. Costs associated with bank reconstruction can be significant and will also need to be taken into account. Bank reconstruction may represent 50% or more of construction costs for a reconstructed channel. Refer to the Integrated Streambank Protection Guidelines for further discussion of bank protection construction costs.

1.6.4 Monitoring and Tracking

Because channel-modification projects generally involve impacts to the channel and banks, they will require comprehensive monitoring of both channel and bank features, in addition to particular attention to habitat monitoring. For a comprehensive review of habitat-monitoring protocols, refer to the Washington Department of Fish & Wildlife's work in progress, "Monitoring Salmon Habitat in Washington State - A Synthesis and Directory of Forty Protocols."

Monitoring of channel-modification projects should be initiated prior to construction, with baseline-conditions surveys of the physical channel, its banks, and its habitat value. This will allow comparison of modified conditions to pre-project conditions. Additionally, monitoring should include detailed as-built surveying and photo documentation of the project area and upstream and downstream reaches to allow for evaluation of performance relative to design. Refer to *Appendix X, Monitoring and Mitigation* for further discussion of monitoring considerations and practices.

1.6.4.1 Geomorphic monitoring

Geomorphic monitoring should include the following at a minimum:

- As-built construction drawings
- Survey of planform, cross-sections, thalweg and bank profiles
- Bed substrate sampling
- Monumented photo points

1.6.4.2 Habitat/Fisheries monitoring

Fish populations are determined by numerous biological and abiotic factors besides physical habitat (Kondolf and Micheli 1995). An increase or decrease in fish populations in a channel following a restoration project therefore may be completely unrelated to geomorphic changes effected by restoration. This is especially true of anadromous populations, which may be controlled in part by fishing pressure, passage barriers, rearing habitat, or ocean conditions (Lawson 1993). Fish populations may be subject to natural fluctuations, and an increase in a fish population may lag years behind improvements in habitat as the aquatic invertebrates and terrestrial food sources develop in response to improvements in bank and channel structure (Kondolf and Micheli 1995). However, habitat and fisheries monitoring may include the following:

- Snorkel surveys of population and use of habitat
- Habitat assessments
- Spawning surveys and redd counts

- Juvenile screw traps
- Migratory box traps
- Macroinvertebrate surveys
- Riparian vegetation surveys

1.6.5 Contracting Considerations

Construction contracting for channel modifications requires careful attention to the specialty nature of the work at hand. Most channel modification projects are very specialized projects that may require specialty equipment and innovative approaches to access and implementation. Selection of a contractor should include consideration of dewatering and in-channel work experience, as well as availability of specialized equipment.

Because channel modification and habitat work often requires the direct supervision of experience habitat construction specialists, a contractor may be unable or unwilling to provide lump sum bids on many project elements. Contracts should, therefore, make allowance for time and materials delivery on certain project elements, such as installation of boulders or wood, creation of bedforms, or other intricate project components.

1.7 Operations and Maintenance

Operations and maintenance requirements will be determined largely by project objectives, and by regulatory agency requirements. These requirements should be carefully integrated with a monitoring plan, such that monitoring results will determine the need for various operations and maintenance.

Various project elements associated with channel-modification projects, such as bank reconstruction and habitat features, may require periodic inspection and maintenance or repair. They may be especially vulnerable to damage during the first years of operation, particularly if they are subjected to high flows before vegetative components are able to provide support. While the intent of channel modification is to create a stable channel, the design must allow some deformity to occur in order to create and sustain adequate fish habitat. For this reason, moderate erosion along banks should be expected and encouraged, and some degree of maintenance and repair should be anticipated especially during the first three years of the new project.

1.8 Examples

Salmon Creek WA, Hardy Creek WA, Whatcom Creek WA – photos and drawings from these examples will be provided

1.9 References

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Schueler, T. 1994. The Importance of Imperviousness. Watershed Protection Techniques, Vol. 1, No. 3, Fall 1994.

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1.10 Photo and Drawing File Names

Photos and drawings from Inter-Fluve projects: Salmon Ck, Whatcom Ck, and Hanna Ck – these are provided and available for review.